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DRX Mechanism for Machine Type Communication (MTC) in Long Term Evolution Network (LTE): Potentials and challenges

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Abstract

Discontinuous Reception (DRX) Mechanism is the power saving technique employed by the Long Time Evolutional (LTE) Network to reduce the power saving. The scheme has seen numerous improvements and tuning to enhance its performance. The Machine Type Communication (MTC) devices have characters that widely differ from the normal devices (Human Type Devices). Therefore, DRX schemes needs to be adjusted to fully accommodate MTC. In this work, a survey of MTC DRX scheme literatures is adapted depicting challenges and potential.

Keywords: *LTE-Advance, machine type communication, MIMO, User Equipment, DRX*

INTRODUCTION

Machine type communication (MTC) is the communication between two or more devices without or with limited human intervention. The communication can be wired or wireless. With the number of advantages wireless communication has over wired communication it is considered more suitable for MTC (also known as machine to machine (M2M) communications (Anas *et al.*, 2023a). Some of these advantages include mobility, scalability and has less infrastructure requirements. The Long Term Evolution (LTE) network is a wireless broadband network which provides high data rate services to user equipment (UE). The data rate is up to 300Mbps for downlink and 75Mbps in uplink. The 3rd generation partnership project (3GPP) a body defining the standards of the LTE, improves the performance of the LTE to LTE-Advanced. LTE-A provides higher data rates of about 1Gbps

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in downlink and 500 Mbps in uplink and also supports higher number of devices. This improvement was achieved by adopting new features such as carrier aggregation, Multiuser Multiple Input Multiple Output (MU-MIMO) antenna technologies, Coordinated Multipoint Operation (COMP), Orthogonal Frequency Division Multiple Access (OFDMA) and Single Carrier Frequency Division Multiple Access (SC-FDMA) for downlink and uplink air interface respectively among others (Anas *et al.,* 2023b). The LTE/LTE-A provides these services at the expense of a highly complex circuitry which is required at both the UE and evolved Node Base station (eNodeB) thus energy efficiency is critical to efficiently utilize the network. Like most wireless devices, UEs are battery powered.

The LTE/LTE-A employs mechanism that extends the UE battery life through series of sleep and wake up cycles called discontinuous reception (DRX) mechanism. The DRX mechanism is enabled in both the two radio resource connection states (i.e RRC_connected and RRC_idle states). The RRC connected state is the state in which UE is known to be active in the network and in this state DRX is enabled to utilize sleep opportunity between packet arrivals (Anas *et al.,* 2022). In the RRC_idle state the UE is inactive and DRX is enabled through a mechanism known as paging cycle. The DRX mechanism saves UE power by putting UE to sleep when it has no outstanding packet to send/receive. However, packets may arrive while the UE is in sleep mode; therefore packet delay is incurred. Also for mobile UE, the need for cell selection of tracking area update may arise while it is in sleep which affects the mobility management of the systems. These issues among others, prompted for the modification of the DRX mechanism to suite various application QoS requirement, mostly, aimed at maximizing power savings with minimum incurred delay.

The standard DRX mechanism is incorporated to suite UE with high data rate demand, frequent network access, highly mobile and delay sensitive. In contrast to these are MTC UEs that are mostly delay tolerant, have low mobility, infrequent network access, uplink transmission and small amount of data transmission. Also these prompted the need for the modification of the DRX mechanism to suite MTC UE. This article is aimed at surveying schemes that modifies the DRX mechanism to suite MTC.

MTC ARCHITECTURE

Machine type communication refers to any communication that does not require human intervention. It cut across several domains from as obvious as metering, pet tracking to industrial automation and fleet management. The size of the MTC device is dependent on its application. Sensors and trackers form the largest category of MTC and they are often of small sizes. The MTC is heterogeneous in terms of application, making it difficult for a single design. However an architecture that defines the components of the machine type communication is provided in which designers follow for intercommunication.

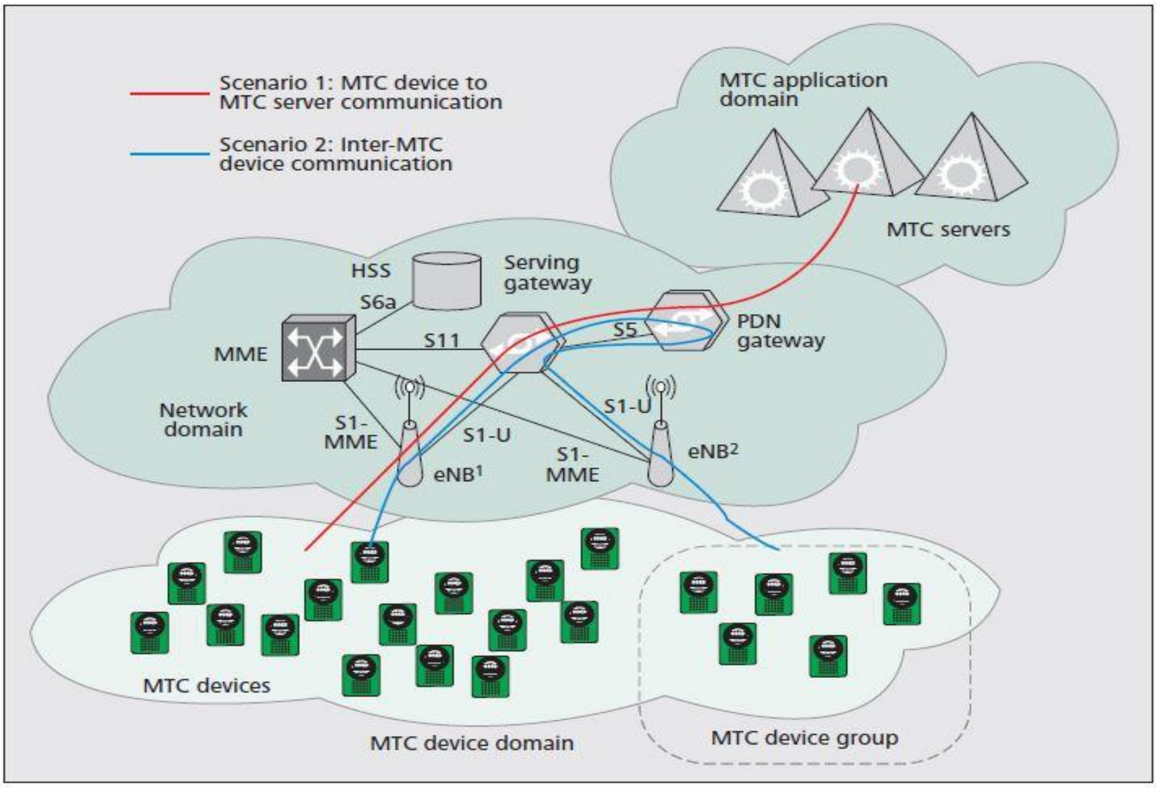

Figure 1 *MTC Architecture from 3G/4G*

The MTC architecture as depicted in figure 1 above consists of three domains, the device domain, network domain and the application domain. The device domain is the lowest part of the MTC architecture where data sensing takes place. The sensed data in being communicated to other devices/servers through the network domain. The network domain consist any access technology that is being used. These technologies can wired or wireless. Different access technologies both wired and wireless were designed to provide means of connectivity to these devices. For the stationary devices, some existing wired access technologies (such as Power line cable, xDSL, optic fiber cable etc.) were used (OECD 2023). The wired access technologies provide high security, data rate, reliability and low latency, but they are costly, lack mobility support and not scalable which makes them unsuitable for M2M. The wireless access mechanism provides solutions to the challenges posed by wired access technologies. It can be categorized into two categories, capillary and cellular wireless access technologies. The capillary access methods (such as Low Power Wireless Local Area Network (IEEE 802.11 LPWAN), ZigBee, Bluetooth, WPAN, RFID, Wi-Fi etc.) are cheap, scalable and support mobility. Nevertheless, these methods have short range, weak security, and supports small number of devices as well as lack standard infrastructure. The wireless cellular access technologies such as 2G (GPRS), 3G (HSPA), 4G (LTE and Wimax) provide wide and good network coverage, supports quite number of devices, highly scalable, secure, highly mobile and have standard ready-to-use infrastructures. Therefore makes cellular technologies suitable for M2M communication.

As an emerging broadband technology, the long term evolution advanced (LTE-A) network provides high data rate services and supports high number of devices. It has a data rate of 1 Gbps in downlink and 500 Mbps (Nakamura, 2009). This is achieved through the use of new features such as advanced antenna technologies (Multiple input multiple output (MIMO)), new access technologies such (orthogonal frequency modulation multiple access (OFDMA), and carrier aggregation, relay nodes and coordinated multipoint operation (in LTE-Advanced). Supporting high number of users LTE/LTE-A employs resource management techniques manage the network resources to provide Quality of Service (QoS) to these users. The radio resource management techniques include scheduling, congestion control, call admission control and power savings. These techniques are carried out by some components in the LTE architecture proposed by 3GPP.

LTE ARCHITECTURE

The network part of LTE architecture comprises of an Evolved UMTS Terrestrial Radio Access Network (3GPP) and the System Architecture Evolution (SAE). The 3GPP consists of evolved Node Base station (eNodeB/eNB). The evolved Packet Core (EPC) is the SAE main component which comprises of mobility management entity (MME), Serving gateway (SGW), public data network gateway (PDNGW/PGW) Home subscriber server (HSS), Policy and Charging Rule Function (PCRF). (3GPP)

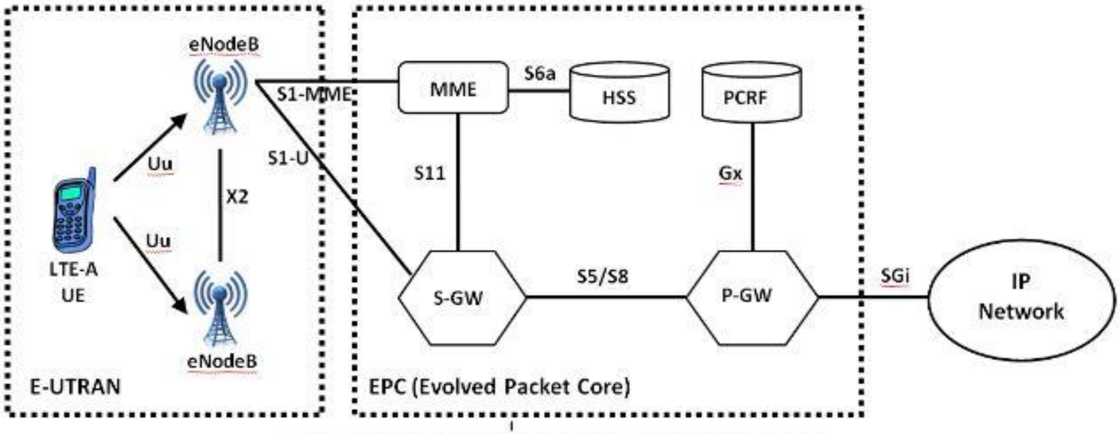

Figure. 2 *LTE Architecture from 3G/4G*

The MME is the component of the EPC that handles signaling exchange between the UEs and the EPC and also between the eNodeBs and the EPC. MME signaling is known as non-access stratum (NAS) signaling as it is carried out by NAS protocol. The MME connects to the eNodeB through the S1-MME interface and connects to the HSS and SGW through S6a and S11 interfaces respectively. MME is a very important component of the LTE as it performs mobility management, authentication, location update, bearer establishment and handover support. The Serving gateway (SGW) acts as local mobility anchor for data bearers as the UE moves between eNodeBs. It routes all the user packet data and for handover between neighboring eNodeBs, it acts like an anchor. When the UEs are idle, SGW maintains UE context and generates paging requests when UE receives downlink data. The Policy and Charging Rules Function (PCRF) is a combination of the charging rules function and the policy decision function that ensures service policy and sends QoS information for each session began and accounting rule information. These policies are enforced in the eNodeB. Home Subscriber server (HSS) is the component used for user authentication and subscription information. The PDN GW provides connectivity to the UE to external packet data networks by being the point of exit and entry of traffic for the UE. A UE may have simultaneous connectivity with more than one PDN GW for accessing multiple PDNs. The PDN GW performs policy enforcement, packet filtering for each user, charging support, lawful Interception and packet screening. It allocates IP address to the mobile and filter downlink packets into different QoS based bearers. With EPC having a "flat" IP architecture, the network handles a great amount of data traffic in an efficient and cost effective manner and support high number of devices. The UE require complex circuitry that drains the UE battery quickly which in turn limit the utilization of the 4G services. As most wireless terminals, UE also are battery powered and the battery production cannot meet up with the requirement, the need for a power saving mechanism in necessary. 3GPP incorporates Discontinuous reception mechanism in LTE/LTE-A to save UE power. (3GPP)

DRX MECHANISM

DRX mechanism is a series of sleep and wake up cycle that UE follows when it has no data to send/receive. DRX mechanism is a power saving mechanism employed by 3GPP LTE/LTE-A to save UE power. DRX discontinuously monitors the physical downlink control channel (PDCCH) and puts the UE into sleep if there is no packet for reception/transmission. During the sleep period the radio transceiver is powered off. The UE periodically wakes up to check for any outstanding packet that might have arrived while it was in sleep. DRX can be activated in two Radio resource control (RRC) states: RRC_connected state and RRC_idle state. The RRC_connected state of UE is when the UE is known by the eNB and evolve packet core (EPC), and the radio is active while the RRC_idle mode refers to the state when the UE radio is inactive, known only by the EPC but not by eNB. In RRC_connected state, upon packet arrival, a timer called inactivity timer (T_i) is started. The timer is restarted if a packet arrives before it expiration. When inactivity timer (T_i) expires (there is no packet arrival after a certain period of time) the UE enters light sleep (short DRX cycle) mode. The light sleep modes comprises of sleep period which the UE powers down it circuitry and an "*ON*" duration in which it listens to PDCCH for outstanding packets. After some consecutive short sleep cycle (N_s), the UE enters a longer DRX sleep cycle called deep sleep (Long DRX cycle) where the sleep duration is increased as compared to the light sleep. If packets arrives while the UE is in sleep state, the packet is buffered till the UE wakes up and it is notified of packet arrival in which it comes out of DRX mode and receive the packet. After a long period of inactivity, the radio resource control release the UE's connections and the UE transit to RRC idle state the UE periodically checks for PDCCH. For every DRX cycle, a sub-frame is assigned. This is called paging occasion (PO). An UE identifier determines the sub-frame number. This can be 0, 4, 5 or 9. When the wakes up a particular PO, it reads the PDCCH and move to connected state if there are outstanding packets destined to it or go back to sleep if there are no packets for it. The DRX mechanism can be seen in figure 3. (3GPP)

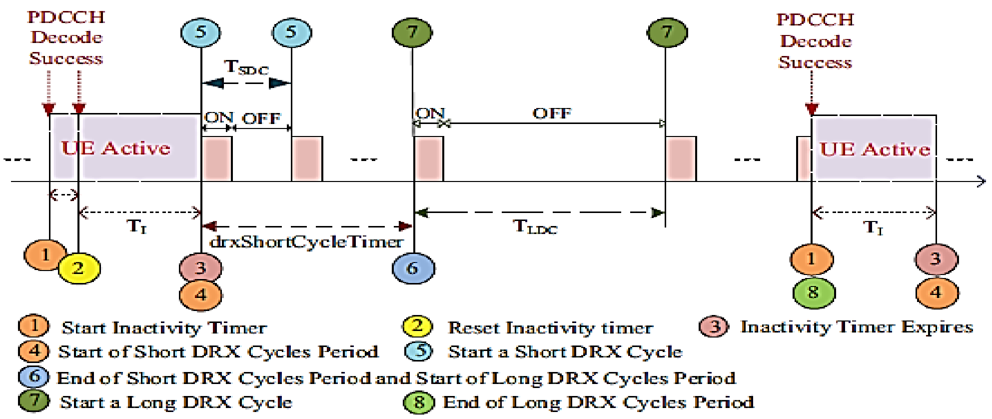

Figure 3 *DRX Mechanisms from Bontu*

RELATED WORKS ON DRX Mechanism for MTC in LTE

Efforts had being made to optimize the performance of DRX mechanism for better QoS in literature. The literatures can be broadly categorized into three categories, those that provide how the DRX parameters (inactivity timer, ON duration timer, short cycle timer, number of short cycles and long cycle threshold) can be set appropriately, those that modified DRX mechanism for normal UEs and those that modified DRX for MTC UEs.

Describing the two states LTE DRX modes (RRC_connected and RRC_idle), Bontu *et al.* (2009), illustrated the parameter set for different applications in DRX mechanism of the LTE networks. This provides basis on how the DRX parameters can be appropriately set without tempering with application's QoS requirement. It was shown that power saving is achieved at the expense of extra packet delay. Trade-off between power saving and packet delay have to made. For delay sensitive (stringent) applications such as video streaming, packet delay is minimized at the cost of extra power consumption. And also for delay insensitive (delay tolerant) such as web surfing, power saving is maximized at the cost of extra packet delay. However, it does not adapt to the changing user activity, intrinsic flaw due to inflexibility of DRX mechanism and power saving analysis was not provided.

Detailed analysis and performance evaluation for DRX mechanism in LTE was presented by Mihov *et al.* (2010). Analytical formulae for determining factors associated with employing DRX on LTE such as delay, power saving factor were presented. The power saving factor and incurred delay formulae are shown in equations 1 and 2 respectively. This aid more accurate evaluation of modified DRX schemes. Nevertheless the analysis only focuses on fixed DRX mechanism and the formulae are complex.

$$\text{PS} = \frac{\pi_2 E[H_2^{eff}] + \pi_3 E[H_3^{eff}]}{\sum_{i=1}^{3} \pi_i E[H_i\ ]} \qquad 1$$

$$\text{Delay}= \sum_{i=1}^{N_{DS}} p_i \frac{t_{DS}}{2} + \sum_{i=N_{DS}+1}^{\infty} p_i \frac{t_{DL}}{2} \qquad 2$$

Fowler *et al.* (2012), presented a simpler formulae (equations 3) for the analysis of both fixed and adjustable DRX mechanism. The analytical formulae captured important DRX parameters which when incorporated can be adjusted to present more accurate results which can be used to validate simulation results.

$$\text{Delay} \sum_{i=1}^{N_{DS}} p_i \frac{C_{DS}^{i}}{2i} + \sum_{i=N+1}^{\infty} p_i \frac{t_{DL}}{2} \qquad 3$$

Liu *et al.* (2013), proposed a scheme that adapts to the changing user activity level by adjusting DRX cycles without incurring signaling cost as well as balancing packet delay and power consumption. Counter Driven DRX (CDA-DRX) counts both active and sleep period in the eNB and UE conformably and adjusts DRX cycle in eNB and UE when one of the counters reaches threshold. Both analytical model and simulation results showed the significant improvement of CDA-DRX over traditional DRX scheme. However, details on how the scheme is to be deployed and power consumption in RRC_idle state are not addressed. Liu and Ren (2015), to keep up with changing UE activity, the proposed scheme adjusts DRX cycle to balance power saving and mean packet delay using thresholds. Effects of thresholds on power saving and mean packet delay are analyzed using two-level Markov model. The results showed that the scheme adapts to the changing user activity level to balance power saving and mean packet delay. However, variable and dynamic operation to cope with different QoS requirement is needed.

Taking the advantages of future channel condition prediction and in-network caching techniques, Moradi *et al.* (2017), proposed two schemes Variable DRX and DRXset that enhances the DRX mechanism. VDRX utilizes any sleep opportunity by modifying the DRX parameters frequently at the expense of signaling cost. With the knowledge of future channel condition, DRXset reduced the signaling cost in VDRX by selecting the DRX cycle length that minimizes the energy usage and providing smooth streaming. An analytical model was used in both schemes and optimization problems are solved using an integer programming solver. However, inaccurate prediction of channel quality affects the scheme as it solely depends on channel condition prediction.

In 2017, Ferng *et al.* (2017), explored the flexibility of DRX and proposed two dynamic and adjustable schemes DADRX-m and P-DADRX. The DADRX-m scheme adds multiple pairs of cycles with varying light and deep sleep cycles. The second scheme P-DADRX uses the pairs in DADRX-m to transit within and/or between the pairs. The result shows the scheme achieved dynamism as it flexibly suites different applications.

The literatures discussed above mainly focused on normal user equipment that demand high data, have both uplink and downlink transmissions, high mobility and frequent network access. For MTC devices that are mostly delay tolerant, with low mobility, infrequent network access, small data burst, and uplink transmission, the DRX mechanism needs to be modified to suite these devices as some of their characteristic contradicts the normal user equipment.

Tirronen *et al.* (2012) show that by extending the sleep length of the standard DRX mechanism, a significant power saving percentage is achieved which extends MTC UEs lifetime by a factor of 6.4. Jha *et al.* (2013), also concludes that by extending DRX cycle length beyond the standard 2.56s second increases UE's power saving and battery lifetime. However, by extending the DRX cycle length beyond 2.56s, the UE may miss the System Information (SI) sent during the modification period (MP).As a solution to the problem, the UE has to read the System information (SI) before DRX active time for it not to miss SI. With this, Kim *et al.* (2014) shows that there will only be gain in power saving if the DRX cycle length is extended beyond 10.24 seconds.

Taking into consideration the amount of power an MTC UE consumed while decoding the computationally complex paging information while in RRC_idle DRX mode, Bulasubramanya *et al.* (2016), proposed a novel mechanism that indicates to the UE to quickly get back to deep sleep when it has no outstanding packet. This is achieved using quick sleep indication (QSI) that is being sent with in synchronization frames. The scheme save UEs power it consumes while reading paging information when it has no outstanding packets. However, the scheme requires modification of the standard DRX scheme to incorporate the QSI information and the amount power consumed in RRC_connected DRX mode is still the same with that of the legacy DRX mechanism.

MTC UEs are known with deterministic transmission interval and characterized with long idle period. Chang *et al.* (2018), explored these characteristics of MTC UEs and proposed a scheme that save UEs power by skipping the short DRX cycle when necessary. An Optimistic

DRX (ODRX) uses an optimistic flag (O_flag) that allows the UE to skip the Short DRX cycle length after the cycle had gone beyond the short DRX cycle. When the data traffic becomes busy, the O_flag adapts to the traffic condition also. Skipping the short DRX cycle, the UE maximizes the potential of longer sleep interval which had been established that it saves power. Nevertheless, the power consumes by the scheme in paging cycle that UE enters quickly is the same as that of legacy DRX mechanism which the UE decode the paging information when it has no outstanding packet. Thus the need for an optimize scheme to maximize power savings is necessarily.

Table 1 Summary of MTC DRX Schemes

S/N	Author	RRC Mode	Algorithm	Strength	Weakness
1	Chang & Tsai (2018).	Connected & Idle.	Optimistic flag	Quick return to deep sleep	RRC reconnection overhead.
2	Zhou *et al.,* (2019).	Connected	Actor critic	Traffic pattern adaptation	Complex computation
3	Wu *et al.,* (2021).	Connected	Bank of expert	Shifted computation to eNodeB	Inefficient learning mechanism.
4	Aghdan *et al.,* (2022).	connected	Dynamic threshold	Traffic adaptation	Computational overhead in tuning of threshold.

CHALLENGES

The DRX schemes in the literature have some common challenges faced

1. **Benchmarks**
   Researchers compare the performance of the proposed scheme with the few schemes of interest and drive to conclusion.
2. **Incomplete Simulation Information**
   This is the major challenges being faced by MTC and DRX researchers. It is almost impossible to replicate the result of a particular research. The researchers deliberately hide any vital information.

CONCLUSION

The researches mainly in the literature focused on MTC are an energy sector with rapid growth of numbers of connected devices. Researches are now geared toward MTC. However, the challenges faced by the sector hinder researches in the area. A benchmark needs to be set on which researchers can use to compare the performance of their scheme. Also there is a need for community that could gear the ease of replication of simulated results.

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